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Recommended Citation

Chen, Rui; Sharman, Raj; Rao, H. Raghav; and Upadhyaya, Shambhu J., "Information Theoretic Approach to Design of Emergency Response Systems" (2008). *AMCIS 2008 Proceedings*. 32.
http://aisel.aisnet.org/amcis2008/32

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Information Theoretic Approach to Design of Emergency Response Systems

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ABSTRACT

Emergency response information systems provide critical support to the disaster management. Despite of the growing interest in this area, the existing research is scanty. A significant limitation is the lack of sound theoretical foundations for emergency management and the information system development. In this paper, the authors adapt Information Theory to explore the theoretical underpinnings of emergency response and discuss the general system design issues.

Keywords

Emergency response, information system design, theoretical foundation, research-in-progress

INTRODUCTION

Emergency response is "*the process of gathering resources and acting upon the problems immediately during and after a critical incident*" (Shen et al. 2004). Emergency incidents may be natural or man-made. Limited information, unpredictable disaster development, short time window, and high operation complexity renders the management of emergency incidents a challenging task (Chen et al. 2007a; Quarantelli 1997; Quarantelli 1998). With the advancement in modern information technologies, information systems designated for emergency management have been practiced and they have proved to play an important role in facilitating the incident management (Bui et al. 2001a; Turoff 2002; Van de Walle et al. 2007b). A number of cutting-edge response systems such as DisasterLAN (www.disasterlan.com), E-Team (www.eteam.com), and Web-EOC (www.esi911.com) have become adopted nationwide. Despite these developments it is widely felt that the current systems are not adequate to deal with the ever-growing challenges in emergency situations (Ashcroft et al. 2002; Burghardt 2006).

In this article, the authors synthesize the existing literature in emergency response information systems design. We adapt Information Theory to explore the theoretical underpinnings of emergency management and discuss response system design. The study is grounded on research in cognitive science, communication, organizational behavior, knowledge management, and coordination theory. The contribution of this paper is threefold. First, the paper synthesizes the literature in emergency response system design and uncovers the significant strengths and limitations. Second, the paper establishes the theoretical foundations for emergency management research and system design. Third, we outline a set of general design guidelines for developing an effective emergency response system.

In the following section, we review the emergency information system literature. Next, we discuss the theoretical framework adopted in this paper and present the design findings. The paper concludes with the agenda for future research.

LITERATURE REVIEW

While "*neither a complete theory of crisis nor a complete theory of organizational crisis management has been proposed to date*" (Pauchant et al. 1992), emergency response system design has been the interest of information system discipline since the 1980s (Belardo et al. 1986; Housel et al. 1986; Wallace et al. 1985). However, the evolvement of this research stream is slow-paced and the existing literature on emergency response systems is scant. Also missing from the current research is a synthesis of the existing findings and a review of the research streams in retrospect. Due to page limit, we discuss only a selective set of journal articles published in the last decade (See Table 1). The review suggests that the existing research of emergency information system may be categorized into four streams: (1) system design for emergency context in general (Chen et al. 2007a; Turoff et al. 2004a), (2) system for specific incident types (Berndt et al. 2007; Bui et al. 2001b; Michalowski et al. 2003), (3) specific decision support features including improvisation (Mendonca 2007), and (4) other considerations (Fruhling et al. 2006; Kim et al. 2007; Papamichail et al. 2005).

Research on emergency information system design for a general context is centered on the development of core design premises and principles that enable system management of "*all-hazard*." Turoff et al. develop a set of general and supporting design principles and specifications for a "*Dynamic Emergency Response Management Information System*" (DERMIS) (Turoff et al. 2004a). Based on historic experience, the authors summarize nine design premises and five design concepts, which consequently contribute to the development of eight general design principles and three supporting design considerations. Chen et al analyze the detailed system requirements and propose the information system requirements to support the operational guidelines in the National Incident Management Systems (NIMS) (DHS 2004). Their study is grounded on the examination of complex interdependencies embedded in the emergency response management: decision, information, resource, workflow, and responder structure (Chen et al. 2007a). The paper also discusses the unique system development challenges to support simple-single, complex-single, and multi-incident contexts.

Meanwhile, researchers have studied the system design for specific incident types. Bui and Sankaran explore the typical workflow in humanitarian assistance and disaster relief scenario and they develop the architecture and a prototype of the virtual information center (VIC) (Bui et al. 2001b). Michalowski et al develop a palm-based mobile clinical support system Mobile Emergency Triage (MET) that uses multilevel clinical algorithms to triage abdominal pain in the emergency room (Michalowski et al. 2003). Berndt et al examine the role of data warehousing in the design of bioterrorism surveillance systems (Berndt et al. 2007). Using data from naturally occurring incidents, the authors apply novel online analytic processing (OLAP) techniques to demonstrate the epidemiologist-in-the-loop surveillance capability enabled by the data warehousing techniques.

Few research works have been focused on the specific design concerns in an emergency information system. Mendonca analyzes the emergency response to the 2001 World Trade Center attack and derives a set of system design requirements for cognitive-level decision improvisation support (Mendonca 2007). Hale develops a layered crisis communication architecture (CCA) that enumerates the communication functionality requirement for emergency information systems (Hale 1997). The layers include connectivity, data-validation, filtering, value interpretation, organizational memory, and group process layers. Mak et al discuss the potential benefits of using workflow approach for crisis management support systems (CMSS) and describe the development of a suitable framework for an existing Swiss government CMSS (Mak et al. 1999).

Fruhling and De Vreede implement the eXtreme Programming (XP) software development method in the development of a web-based and distributed emergency response system (Fruhling et al. 2006). Papamichail and French propose methods for assessing the quality of emergency information systems (Papamichail et al. 2005). These methods are technical verification, performance verification, and subjective assessment. Kim et al develop and validate survey instruments that evaluate the efficiency of critical incident management systems (CIMS) (Kim et al. 2007). The measurements include eight constructs and twenty-eight items in total.

This review suggests that the research in emergency information system is still at its infancy. Despite of the few pioneer works, much remains unknown to the information system domain in terms of how to design an effective and "*prescriptive*" response information system (Hale 1997). In this paper, we draw on relevant literature in other fields to explore the theoretical underpinnings in emergency management and system design.

Author (s)	Year	Publication	Paper Title	Key Research Issues and Findings	Research Type
J.K. Kim et al.	2007	Decision Support Systems 44 (1)	Efficiency of critical incident management systems: Instrument development and validation	Development and validation of an instrument to measure the critical factors contributing to the efficiency of decision support in incident management systems	Empirical
D.J. Berndt et al.	2007	Decision Support Systems 43 (4)	The role of data warehousing in bioterrorism surveillance	Exploration of the role of data warehousing in bioterrorism surveillance and the use of online analytic processing techniques to study the effects of disasters	Design science, case study
D. Mendonca	2007	Decision Support Systems 43 (3)	Decision support for improvisation in response to extreme events	A set of requirements for computer-based systems intended to support improvisation in response to extreme events	Theory building, Case study
J. Mustajoki et al.	2007	Decision Support Systems 42 (4)	Interactive computer support in decision conferencing: two cases on off-site nuclear emergency management	Requirements for the facilitation and computer support in the use of advanced multi-criteria decision conferencing software	Design science, case study
R. Chen et al.	2007	Information Systems and E-Business Management 5 (3)	Design principles for critical incident response systems	Development of design principles that are grounded in emergency management concepts and practice	Theory building
A. Fruhling and G.J. de Vreede	2006	Journal of Management Information Systems 22 (4)	Field experiences with eXtreme programming: developing an emergency response system	Report of the experiences of implementing the XP methodology in a development project for a Web-based, distributed emergency response information system	Action research
K.N. Papamichail and S. French	2005	Decision Support Systems 41 (1)	Design and evaluation of an intelligent decision support system for nuclear emergencies	Classification of methods for assessing intelligent decision support systems and discussions of an intelligent decision system for nuclear emergencies	Design science, empirical
M. Turoff et al.	2004	Journal of Information Technology Theory and Application 5 (4)	The design of a dynamics emergency response management information system	Development of a set of general and supporting design principles and specifications for a "Dynamic Emergency Response Management Information System" (DERMIS)	Theory building
W. Michalowski et al.	2003	Decision Support Systems 36 (2)	Mobile clinical support system for pediatric emergencies	Design and development of a mobile support system to triage abdominal pain in hospital emergency room	Design science
T.X. Bui and S.R. Sankaran	2001	Decision Support Systems 31 (2)	Design considerations for a virtual information center for humanitarian assistance/disaster relief using workflow modeling	Analysis of the workflow in a disaster scenario and discussion of the design considerations for a virtual information center (VIC) which supports disaster preparation/management/recovery teams	Theory building
H.Y. Mak et al.	1999	Decision Support Systems 25 (3)	Building online crisis management support using workflow systems	Discussion of the potential benefits of using a workflow approach for CMSS and the development of a suitable framework for an existing Swiss government CMSS	Case study
J. Hale	1997	Journal of Management Information Systems 14 (1)	A layered communication architecture for the support of crisis response	Development of a prescriptive architecture for crisis response systems with the role of communication and the characteristics of communication systems	Theory building

Table 1. Review of Selective Emergency Response Information Systems Literature

THEOREICAL FRAMEWORK DEVELOPMENT

In this paper we study the emergency information system design through the lens of an adapted Information Theory (Shannon et al. 1949). Information Theory describes communication as a process consisting of an information source, message, transmitter, signal, noise source, communication channel, receiver, and destination. In its essence, the theory suggests that, in order to communicate information among entities, the information is usually encoded by the transmitter and later decoded by the receivers who receive it; the information transmission may be influenced by the attributes (e.g., channel noise and capacity) of the communication channels. While established as a mathematical model for the engineering research on information transmission, Information Theory has been well adapted to portray the communication and information sharing phenomena in more broader social and technical contexts (Covello et al. 1986; Leiss 1989). Key theoretical tenets such as "encoding," "decoding," "noise," and "channel capacity" are found parallel to the similar processes in individual and organizational activities and general information system design as well (Daft et al. 1987; Fitts 1992; McCanne et al. 1997; Nonaka 2002). Communication and information sharing are critical to emergency response as they connect the key elements of crisis management and enable the critical processes such as sense making and decision making (Turoff et al. 2004a). An Information Theory informed theoretical lens therefore provides a flexible framework to investigate the emergency management phenomena and to derive the design requirements for an effective emergency information system (Hale 1997).

We adapt Information Theory into emergency response system context as in Figure 1. The application of Information Theory views emergency management through an information processing perspective. Decision makers collect raw scene information for sense making and decision making. They may share and communicate with each other for collaboration and coordination. Communication channels provide vital support to these processes while they are subject to noise. The processed information is ultimately stored at their destination. This adapted model is symmetric in nature and it describes emergency management activities at both individual and group levels. Through the lens of the adapted Information Theory, we discuss managerial issues and present the findings of response information systems designs.

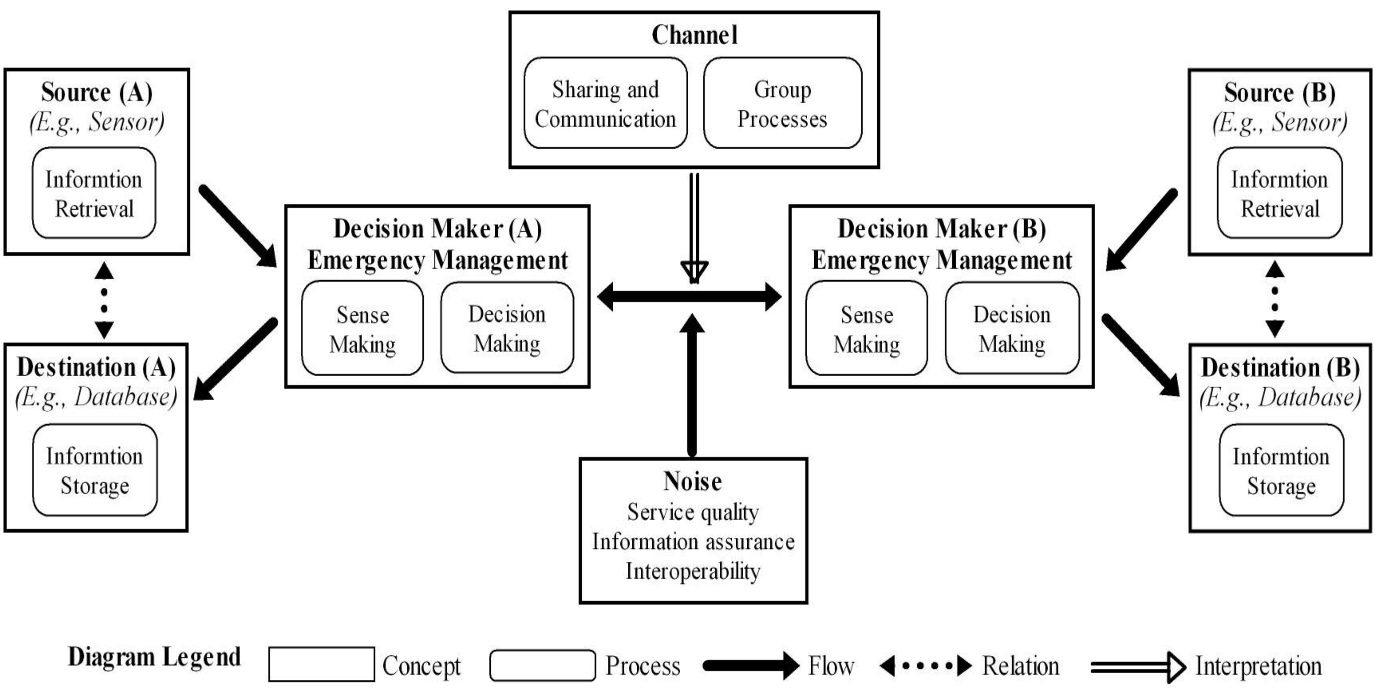

Figure 1. Adaption of Information Theory in Emergency Management and System Design

Source of Information

Information sources provide the task-critical data for decision makers in emergency management. Typical information sources for emergency response may include sensors, surveillance camera, alert network, and monitoring systems (Townsend 2006). In case of unified incident command, each of the collaborating agencies brings in unique information, accessible through their internal data sources only. For example, the public-workers provide information, from their internal systems, on the location of resources for clean-up.

Crises are characterized by a high level of uncertainty and requires "*quick action that deflects a triggering event as it unfolds rather than delayed action that mops up after trigging event has run its course*" (Weick 1988). Organizational literature such as Information Processing Theory suggests that uncertainty is amendable through the increase in information. Galbraith defines uncertainty as "*the difference between the amount of information required to perform the task and the amount of information already possessed by the organization*" (Galbraith 1973). It is therefore evident that the emergency management regularly maintains and operates a satisfactory level of information sources during incident response period (Brass 1985; Wong et al. 2004). Literature on High Reliability Organization (HRO) and Reliability Seeking Organizations (RSO) suggests that the diversity of information sources, in forms such as satellite image, telephone, and facsimile, offers media-rich information and assists emergency-dealing organizations in avoiding simplifying interpretations of the facts (Rijpma 1997; Vogus et al. 2003). An appropriate information processing capability is recommended so as to leverage all available information in heterogeneous formats (Wimberly 2004).

Other challenges to information sources are acknowledged in the prior research of disaster management. Chen et al suggest that information on emergency incident is likely to be tainted and prone to mistakes (Chen et al. 2007a). For instance, eye-witness accounts of the scene are often biased by their comprehension processes, background, recollection, and verbalization skills. As a consequence, triangulation-based data validation (Douglas 1976; Webb et al. 1965) is an indispensable component for emergency response information systems (Hale 1997). The validation usually relies on multiple and independent sources to validate an event, fact, or conclusion (Bernstein et al. 1974; Downs 1967). Designs using data correlation and mining techniques have proved to be adequate solutions (Chen et al. 2003a; Chen et al. 2003b). Reference databases are also advertised for employment as they enhance the system competence in logic reasoning and inconsistency detection (Turoff et al. 2004a).

Decision Makers

Emergency incidents occur at low probability and high consequences (Hale 1997). Because of their low probability, "*these events defy interpretations and impose severe demands on sense making*" (Weick 1988). Sense making is the process of creating situational awareness and understanding in situations of high complexity or uncertainty in order to make decisions. Ajenstat et al suggest that emergency are often qualified as '*ill*' or unstructured decision processes, associated with "*messy*" problems, or linked to ambiguous and uncertain environments; they all therefore critically test human cognitive limitations and organizational capabilities (Ajenstat et al. 2007). It is therefore crucial that emergency information systems incorporate designs on sense making support (Turoff et al. 2004a). Individual sense making involves the cognitive activities of constructing hypothetical mental models of the current situation and how it might evolve over time, what threats and opportunities for each action are likely to emerge from this evolution, what potential actions can be taken in response, what the projected outcomes of those responses are, and what values drive the choice of future action.

Military literature of Network-Centric Operations (NCO) suggests that the sense making relies on enhanced situational awareness in extreme contexts (Garstka et al. 2004). Biros et al define situational awareness as *"the decision-makers' moment-by-moment ability to monitor and understand the state of a complex system and its environment*" (Biros et al. 2004). During emergency, the completeness and accuracy of decision makers' situational awareness is crucial to their abilities in comprehending the disaster facts, hazards and risks, and mitigation capabilities, which "*piece together an accurate of reality*" (Hale 1997). System designs such as information infusion are advised in this regard. Field interviews with emergency responders find that incident information may expand rapidly during the course of mitigation; the increasing level of response enactment (Weick 1988) accumulates new information on incident, responder, resource, operation, and environment from all stakeholders. This multi-dimension information cross interrelate with each other and together match the high "*requisite variety*" (Weick et al. 1999) of the decision problems in extreme events. Literature on Cognitive Processing Capacity (CPC) suggests that individuals are limited in cognitive resources and incapable to allocate them optimally for problem solving (Britton et al. 1982; Sweller 1988). In the face of information of large volume and high complexity, emergency managers are prone to be "*overloaded*" (Auf der Heide 1989). The mental stresses resulted by time pressure, perceive risks, and concerns on "*public image*" further intensify the cognitive overload (Kim et al. 2007; Paton et al. 1999). To this end, tactics such as information filtering are recommended by prior emergency studies so as to reduce the amount of irrelevant data, organize related messages into cohesive and coherent sets, and prioritize message sets according to level of importance (Bui et al. 2001b; Chen et al. 2007a; Hale 1997; Turoff et al. 2004a). In addition, research on Human Computer Interaction (HCI) suggests that cognitive overload may be reduced through design schemes in interface structure, information packaging, and information accessibility (Chen 2007; Kim et al. 2003).

Situational awareness is the prerequisite to information assimilation and accommodation in line with Theory of Cognitive Development (Piaget 1972; Piaget 1977). To interpret newly acquired incident information, individual responders exercise existing cognitive schemas to value the meanings of the messages (Sweller 1988). Sohlenkamp et al point out that both present and past awareness information are supportive (Sohlenkamp et al. 1997). The present information enables the "*lateral analysis*" of concurrent events while the past information (e.g., experience gained in managing similar dealings) helps the decision makers to leverage the existing body of knowledge for current mitigation practices (Turoff 2002). Together they reduce the "*cognitive gap*" which hampers the understanding of new information (Dervin 1983; Dervin 1992). Signal Detection Theory (SDT) posits that this ultimately helps the responders increase their rate of "*hits*" in capturing valuable information while decreasing the rate of "*miss*" or "*false alarm*" (Swets et al. 1982). Existing findings on disaster management advocates the system design of "*crisis memory*" (Hale 1997; Turoff et al. 2004a). A crisis memory records the historical track records of past incidents and the current response event as well. The crisis memory is typically developed at emergency pre-planning stage and it may be implemented through event log and knowledge base designs (Hale 1997).

The awareness and understanding leads to the improved decision making (Garstka et al. 2004). Decision making in extreme events is an understudied research area and the prior studies point out that the classical decision theories may not be valid in explaining how individuals make decisions at trying conditions (Bond et al. 2006; French et al. 2005). Crisis situations are inherent with unexpectedness, uncertainty, nonroutiness, and significant consequence (Shen et al. 2005). Each of these places high demands on decision making; when combined, they introduce extreme complexity in the decision problems and "*create a unique and threatening decision-making environment that must be conscientiously supported*" (Hale 1997). March and Shapira suggest that, at disorderly action case such as emergency situation, decisions become collections of problems and solutions linked by simultaneity more than by causal association (March et al. 1982). The Garbage Can Theory (GCT) adds that decision making in extreme events "*is a collection of choices looking for problems, issues and feelings looking for decision situations in which they might be aired, solutions looking for issues to which they might be the answer*" (Cohen et al. 1972). In his Recognition-Primed Decision Theory (RPD), Klein points out that individuals make decisions based on the recognition of past experiences that are similar to the current situation (Klein 1989). Instead of a thorough research of the decision problems and solution domains, individuals use unstructured process to make quick decisions in threatening environment. That is, they rely on prior experience to spot the most "*intuitive*" solution that is plausible and return to the other alternatives only when the existing one fails (Klein 1999). The above discussion highlights the importance of crisis memory to the emergency response information system design. This can be further augmented by digital archives of preplanning materials including risk assessment, layout of critical infrastructure, analysis of infrastructure interdependence, and all-hazard mitigation plans (Mak et al. 1999). A comprehension of relevant knowledge in historical incident management, existing plans, and the up-to-minute update on current incident development reduce the efforts for decision makers to "*mix-and-match*" (Mendonca 2007) the decision problems with emerging potential solutions.

Channel

Modern emergency management employs a variety of communication channels including LAN, WAN, ad-hoc wireless network, mesh network, 800M Hz radio, and satellite phone (Anderson 1991; Beroggi et al. 1995; Dawes et al. 2004). During any typical emergency operation, hundreds of task critical updates, briefings, reports, requests, queries, and orders are circulated inside the incident management organizations (Chen et al. 2005). These channels enable real-time information sharing and communications, establishing a "*common operational picture*" to keep all the decision makers on the same page (Carafano 2003; Midkiff et al. 2002). A common operational picture is a single identical display of relevant operational information shared by more than one actor. Through information transfer, responders working on varying aspects of the mitigation tasks are able to synchronize their visions on the focal incident, smooth out potential inconsistencies, and synthesize a complete "*shared mental model*" (Bui 1992). Information sharing mechanisms such as "*publish / subscribe*" system are recommended for this regard. Further, communication channels support collaborative group processes such as group decision making, collaboration, and coordination (Bui et al. 2001b; Chen et al. 2005; Hale 1997; Hiltz et al. 2005; Hiltz et al. 2004; Turoff et al. 2004a; Turoff et al. 2004b). A typical emergency response involves multiple stakeholders such as police, fire company, emergency medical service, and Haz-Mat workers; when incident escalates, the management effort may be augmented by government agencies at city, county, state, and federal levels as well as representatives from nonprofit and private organizations (Chen et al. 2007b). Group processes are therefore important to allow all the stakeholders to share viewpoints, generate synergy, and leverage collective capabilities to an optimal level (Chen et al. 2005). Information system designs such as group decision support, negotiation, and feedback may suffice the requirements to support group processes. Research in Computer-Supported-Cooperative-Work (CSCW) underlines the importance of "*physical proximity*" for group performance (Bui 1992; Winter 1985). System designs in form of video conferencing are suggested.

While it is generally accepted that communication may improve response, communication can be costly and even unaffordable unless properly managed (Chen et al. 2005). Research in organizational science, communication, and computer science has proposed plausible solutions reducing the communication going in- and out- of individuals. Resource Dependence Theory (RDT) proposes that actors lacking in essential resources (e.g., information an knowledge) will be dependent upon others in order to obtain needed resources (Pfeffer et al. 1978; Ulrich et al. 1984). Emergency responders may choose to reduce the level of dependencies through self-containment practices including training, education, and maintenance of own information and knowledge repository. Information system designs such as digital archives of reference material and knowledge base may suffice this requirement. Transactive Memory Theory (TMS) adds that the efficiency of interpersonal communication increases if the individuals knows "*who knows what*" in the organization (Wegner 1987; Wegner et al. 1985). Transactive memory is the share division of cognitive labor with respect to the encoding, storage, retrieval, and communication of information from different knowledge domains (Wegner 1987). It is suggested that when individuals develops transactive memory they will begin to know who to communicate, what to communicate, and when to communicate in the organization (Brandon et al. 2004). Given the fact that emergency management team is rather unstable and is absent of shared meta-structure, Majchrzak et al suggest remedies to cultivate transactive memory among emergency response organization (Majchrzak et al. 2007). At information system design level, these remedies may translate to the implementation of personnel directory and "*community narratives*" (Boland et al. 1995). Last but not least are the computing technologies such as data compression which reduces the communication load (Nelson et al. 1995; Witten et al. 1987).

Noise

Emergency channel is exposed to all sorts of noise including threats to channel performance, information assurance, and communication interoperability. Channel performance measures the communication capacity, connectivity reliability, channel accessibility, and system adaptability. The existing emergency system literature has identified and evaluated a set of solutions which include increased technology investment, partnership of public/private network, load balancing scheme, priority telecommunication services, and redundancy design (Berge 1990; Hale 1997; Manoj et al. 2007; NCP 2006; Turoff et al. 2001). Information assurance refers to information security and privacy. Security is a key element to emergency communication as long as sensitive information is present; it continues to be focal concern for channel design considering the increasing awareness of terrorist attacks (Chen et al. 2004). System designs such as encryption, decryption, and intrusion detection may suffice the security requirement. Privacy is a more recent issue facing emergency management nowadays. Existing regulations such as HIPPA (Health Insurance Portability Accountability Act of 1996) require that privacy information including personal identity and medical history be carefully handled (Congress 1996). The interoperability issue is pronounced for emergency management because the technologies adopted by participating agencies to support the mitigation of a critical incident are in general incompatible for reasons ranging from the ability of local agencies to fund technology to the lack of unified guidelines for software and hardware (BJA-DOJ 2007; Fedorowicz et al. 2007; Gogan et al. 2005; Williams et al. 2005). To this end, it is extremely important that the emergency response community as a whole develop consistent data standards, transmit protocols, homogenous devices, compatible application interfaces, and congruent regulations (Aylward et al. 2006; Chen et al. 2008; DHS 2005; Frale 2005; Harrison et al. 2006). Examples include the National Information Exchange Model (www.niem.org), Emergency Data Exchange Language (www.comcare.org/edxl.html), Common Alert Protocol (www.incident.com/cap), SAFECOM initiative (www.safecomprogram.gov), and Federal Enterprise Architecture (www.whitehouse.gov/omb/egov).

Destination

The destination of emergency information in large consists of database, data warehousing, knowledgebase, etc. These areas are where the modern computing technologies contribute most and are well studied in the emergency research (Berndt et al. 2007; Breitbart et al. 1986; Chen et al. 2003b; NEMSIS 2007; Van de Walle et al. 2007a; Van de Walle et al. 2007b).

SUMMARY OF THEORETICAL FUNDATIONS AND DESIGN PRINCIPLES

Major Information Theory Constructs	Key Management Issues	Key Background Literature	Key Design Options and Features
Source of Information	Reduction of task uncertainty	Information Process Theory	Regularity of information source maintenance and operation
	Reluctance to simplify interpretation	High Reliability Organization Theory and Theory of Reliability Seeking Organization	Increased diversity of media types, multi-media processing capability
	Improvement of Information validity	Emergency response literature	Triangulation-based data validation, data correlation mechanism, data mining technique, reference database
Decision Maker	Achievement of situational awareness	Theory of Network-Centric Operation	Information infusion technology
	Reduction of cognitive overload	Law of Requisite Variety, Theory of Cognitive Processing Capacity, Human-Computer Interaction Research	Relevance-, coherent-, and priority-based information filtering, interface structuring, information packaging, and information accessibility schemes
	Ease of information assimilation and accommodation	Theory of Cognitive Development and Signal Detection Theory	Crisis memory
	Rapid decision making	Garbage Can Theory and Recognition-Primed Decision Theory	Digital archive of preplanning, case-based reasoning system
Channel	Achievement of common operational picture	Shared Mental Model literature	Publish/Subscribe systems
	Support of collaborative group work	Computer Supported Cooperative Work	Group decision support, group negotiation system, feedback system, video conferencing
	Reduction of communication cost	Resource Dependence Theory and Transactive Memory Theory	Digital archive of reference material - common platform for easy retrieval, knowledgebase, personnel directory, event-log, wiki-based community narrative system,
Noise	Improvement of channel capacity	System quality literature	Partnership of public/private network, load balancing scheme, priority telecommunication services, and redundancy planning
	Achievement of information assurance	Security and privacy literature	Encryption, decryption, and intrusion detection
	Improvement of communication Interoperability	Interoperability literature	Consistent data standards, transmit protocols, homogenous devices, compatible application interfaces, and congruent regulations

DISCUSSION AND CONCLUSION

Emergency response is an important but challenging research topic. Conventional wisdoms in management and information system design need to push their definitional limits and theoretical boundaries to help individuals, when they are "*struggling to collaborate under extreme time pressure and risk, with inadequate information, with emotionally laden volition, and with others who have conflicting purposes, fleeting involvement, and changing perspectives*" (Majchrzak et al. 2005). In this paper we synthesize the prior literature in related areas. We further explore the theoretical foundations of emergency management and propose design guidelines.

Due to the page limit, we are not able to delve into the details of all the issues mentioned in the current paper. Future research is required to review these untouched issues such as conflicting system requirements, system implementation, user training, and system adoption. While some of these issues may be explained by conventional information system (IS) theories, many of them may require different, even counterintuitive, solutions. Future research also includes an extension to the exiting literature review as to cover the other important publications and synthesize them into appropriate streams.

ACKNOWLEDGMENT

This research has been funded by NSF under grant 0705292. The usual disclaimer applies.

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